

Fig 1. The phylogenetic relationships among different species of *Lycium* were analyzed based on two sequence fragments, waxy and trnT-trnF. Different colors indicate their geographical origins, and the species within the box exhibit sexual dimorphism. (Levin and Miller 2005).

There are 7 species and 3 varieties of *Lycium* species naturally distributed in China, and 5 new species have been published in recent years. *Lycium amarum* L.Q. Huang from Tibet is a new bitter species with regional representation at high altitude. Three key species have been widely used as medicinal and economic crops. *Lycium barbarum* L., *Lycium ruthenicum* Murr. and *Lycium chinense* Mill. in China are the three closest sister species, commonly named **Goji or Goji berry**. They can be clearly distinguished from other closely related species, indicating that *Lycium* species in China have experienced a unique evolution process under specific geographical conditions.

Goji is widely distributed in China and has strong environmental adaptability. Plants grow in alpine meadows, deserts and low mountains and hills. The soil types include desert, swamp peat, saline alkali land, alkaline clay, acid red yellow soil and acid humus soil. The light conditions range from the Tibetan Plateau with strong light to the Sichuan basin with weak light, and the climate ranges from the arid and semi-arid northwest to the southwest and southeast regions with high temperature and humidity.

Table 1. The distribution characteristics of the three key species.

Species	Main distribution area	Ecological characteristics
<i>L. barbarum</i>	Xinjiang, Tibet, Qinghai, Gansu, Inner Mongolia, Ningxia, Shaanxi, Shanxi, Hebei and other northwest and northern regions	Strong adaptability to drought, salinity and low temperature.
<i>L. chinense</i>	Guangdong, Fujian, Shandong, Hubei, Yunnan, Hebei and other Central, southwest and Southeast China	Widely distributed; fruit cultivation areas are gradually reduced, and vegetable cultivation areas are extensive.
<i>L. ruthenicum</i>	Ningxia, Gansu, western Qinghai, Xinjiang, western Inner Mongolia and Tibet	The most saline alkali tolerant species of <i>Lycium</i> in China, which can be used as a pioneer plant in saline alkali land



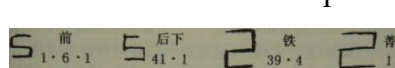
Fig. 2 Three key Chinese medicinal *Lycium* species

The bright orange red of *Lycium barbarum* fruit in Ningxia comes from fat soluble carotenoids, especially *Lycium barbarum* erythroid (zeaxanthin dipalmitate). *Lycium ruthenicum* is purple black because it is rich in anthocyanins. The Mongolian medicine is named "jonoyin halmag" and the Tibetan medicine is named "POMA". Uighur Medicine records that Uighur doctors often use black wolfberry fruit and root skin to treat urethral calculi, tinea scabies, gingival bleeding, etc; According to Tibetan medicine classics such as the four medical classics and Jingzhu Materia Medica, it is used to treat heart fever, heart disease, irregular menstruation, etc.

The contents of calcium, iron and niacin in *Lycium ruthenicum* were 2.3, 4.6 and 16.7 times higher than those in *Lycium ruthenicum*, respectively. The content of procyanidins was 3690 mg/100g, which was higher than that of Blueberry (330-3380 mg/100g). *Lycium ruthenicum* polysaccharides have hypoglycemic, anoxic, anti fatigue, lipid-lowering, antioxidant, anti radiation damage and vascular protection effects.

2. Historical and written records of Goji

In oracle bone inscriptions (1250-1046 B.C.), there have been the words "Ji"



and "Qi" , both sound like Goji. However, these two words were not *Lycium* species, instead referring to one traditional economic species (*Salix integra* Thunb. belong to Salicaceae) used for making willow baskets. So, The written record of Goji was first found in "The Book of Songs" 《诗经》, the earliest Chinese poetry anthology, and "The Classic of Mountains and Seas" 《山海经》, an ancient compendium of geography and natural lore. So, the first written record should be about 3000 years ago.

In "The Book of Songs"(about 3000 years ago, Zhou Dynasty of ancient China), there are 7 places recording the scenes related to Goji. For example, in *Odes-Guofeng: Jiang Zhongzi*, the verse "Do not break my planted qi" indicates that Goji tree was already under protection as a special woody species at that time. In *Xiaoya-Si Mu*, old poem suggests that Goji plant grew abundantly in dense stands. In *Xiaoya- Du* and *Xiaoya-Bei Shan*, the verse "I climb the northern hills to gather qi" records the harvesting scene of Goji trees. All these passages fully demonstrate the high regard in which Goji plant was held by people of that era.

"The Classic of Mountains and Seas" (about 2500 years ago, the Warring States period of ancient China) record "Qi" fruit trees that are all *Lycium* plants. It also records red juice of Goji berry like human blood, suggesting that human beings in primitive society have some understanding of the nutritional function of Goji berry.

3. Applications of Goji as both medicine and food in ancient Chinese books

The application records of Goji for both medicine and food in ancient books was first found in the earliest monograph on traditional Chinese medicine *Shennong's Classic of Materia Medica* in the Han Dynasty (《神农本草经》, 2200 years ago). Goji is first recorded here as "Upper-Grade Wood Herb": "It is bitter-tasting and cold in nature; it treats pathogenic qi in the five internal organs, internal heat with wasting-thirst, and general bi-obstruction. Long-term consumption strengthens bones and tendons, lightens the body, and retards senescence. It is also named qigen, digu, gouqi, and difu. It grows in flat marshy lands." What is described in this text most likely refers to modern-day *Cortex lycii radialis* (the root-bark of Goji-berry, also known as digupi). It grew in the flat marshlands of ancient

Changshan State, roughly present-day Xingtai in Hebei Province, and its botanical origin should be *L. chinense* Mill.

In *Materia Medica for Famine Relief* (《救荒本草》 about 620 years ago, Ming Dynasty), old record is “12 feet long, several inches in circumference, without thorns, and had cherry-sized fruits”. Its consumption methods are described as follows: “Blanch the young leaves, rinse them clean with water, season with oil and salt for eating, or cook them into soup. The ripe red fruits are also edible. When thirsty, boil the leaves to prepare a beverage as a substitute for tea.” This fully illustrates the dual medicinal-edible utilization modes of Goji leaves and fruits.

Root bark (*Cortex Lycii Radicis*) is an extremely important Chinese herbal medicine. *Decoction Materia Medica* (《汤液本草》) states: “Cortex Lycii, purging the kidney fire, reducing the underlying fire in the lung, removing the fire in the cell, and reducing fever.” *Seeking Truth in Materia Medica* (《本草求真》) records: “Cortex Lycii is used for bone-steaming fever, sweet and effective for bone-steaming accompanied by sweating.” These records document that root bark is sweet-tasting and capable of treating bone-steaming fever with sweating.

In *Compendium of Materia Medica* (Bencao Gangmu 《本草纲目》), author Li Shizhen, the great medical scientist and pharmacologist from Ming Dynasty, firstly interprets the name “gou qi”: “It has thorns of gou and twigs of qi, therefore named gou-qi.” According to this book: leaves harvested in spring are *TianJingCao*; flowers in summer *ChangShengCao*; fruits in autumn *GouQiZi*; roots in winter *DiGuPi*. Since all plant parts can be gathered year-round for use, goji was highly valued in antiquity.

From the pre Qin period to the Tang and Song Dynasties, Goji has been known and used by Chinese people, and its efficacy has been well documented in the herbal medicine of past dynasties. These texts clearly document the actions of goji: tonifying the kidney and replenishing essence, nourishing the liver to improve eyesight, and moistening the lung to nourish yin. The original records are as follows:

Materia Medica for Dietetic Therapy (Shiliao Bencao) records: “Leaves and fruits: strengthen sinews, dispel wind, tonify sinews and bones, benefit the human body, and relieve consumptive debility. Roots: primarily treat bone-steaming heat and wasting-thirst. Leaves cooking with mutton into soup can benefit health. For a tea substitute, boil leaves can boost sexual function and relieve wind-induced itching and red membranous opacity of the eyes.”

Records of Famous Physicians (Mingyi Bielu) states: “Goji disperses constrained qi in the chest and hypochondria, relieves headache caused by exogenous heat, tonifies internal injury and severe overstrain, improves laboured breathing, strengthens sinews and bones, tonifies kidney yin, and promotes urination and defecation.”

Treatise on Medicinal Properties (Yaoxing Lun) notes: “Goji tonifies essence and qi, remedies all kinds of deficiency, improves complexion, turns grey hair black, brightens eyes and calms the spirit, and prolongs life. When thirsty, it may be boiled as a tea. Cooking its leaves with mutton in soup benefits health and relieves summer-heat damage.”

Compendium of Materia Medica (Bencao Gangmu) writes: “Goji is sweet and neutral in nature, acts on the liver and kidney meridians; it tonifies and nourishes the liver and kidneys, replenishes essence and brightens vision.”

Decoction Materia Medica (Tang-ye Bencao) records: “Goji fruits are indicated for heart-system disorders with throat dryness and cardiac pain, thirst with polydipsia, and kidney-originated wasting-thirst.”

Essentials of Materia Medica (Bencao Beiyao) states: “Goji moistens and clears the liver, nourishes the kidney and boosts qi, generates essence and assists yang, relieves consumptive overstrain, strengthens sinews and bones, dispels wind to brighten eyes, promotes urination and defecation, and treats throat dryness and wasting-thirst.”

4. Ancient records for making pills and medicinal wines

Validated Prescriptions Recorded in Ancient and Modern Sources (Gu Jin Lu Yan Fang) records pills prepared solely from goji fruits for the treatment of consumptive injury and deficiency.

Standards for Diagnosis and Treatment (Zheng Zhi Zhun Sheng Fang) documents pills composed of goji and polygonatum to treat consumptive debility, essence depletion, lassitude and mental fatigue. It also records Goji wine made by macerating goji fruits in wine, indicated for lacrimation upon wind exposure due to liver deficiency.

Secret Texts on Health Preservation (She Sheng Mi Pou) records the Goji Syrup from goji berries and longan aril. It nourishes yin, improves mental acuity, tonifies blood and calms the spirit.

Wonderful Prescriptions for Health Preservation (She Sheng Zhong Miao Fang) documents Goji tea, which is produced by grinding goji fruits and schisandra berries, then infusing the powder with boiling water as a tea substitute. It treats summer-debility disorder characterized by poor appetite, emaciation, lassitude and fatigue in hot summer.

Medical Grades (Yi Ji) records Qiju Dihuang Wan (Goji-Chrysanthemum Six-Ingredient Rehmannia Pill) combining goji, chrysanthemum and Liu Wei Di Huang Wan for dizziness, dry blurred vision, wind-induced lacrimation and photophobia caused by liver-kidney insufficiency.

Standards for Diagnosis and Treatment (Zheng Zhi Zhun Sheng Fang) records Gui Lu Er Xian Jiao (Tortoise-Deer Two Immortals Gel) using goji together with tortoise shell, deer antler and ginseng to nourish yin and support yang. Long-term administration can greatly tonify essence and blood, replenish qi and nourish the spirit.

Complete Works of Jingyue (Jing Yue Quan Shu) records Zuo Gui Yin (Left-Restoring Decoction) formulated with goji, rehmannia root, Chinese yam, cornus fruit, poria cocos and licorice, treating yin-deficiency tidal fever, night sweats and cough caused by kidney yin insufficiency and flaming deficient fire.

Complete Works of Jingyue (Jing Yue Quan Shu) records Xiao Ying Jian (Small Nourishing Decoction, also from * *), composed of goji, peony, angelica, rehmannia, Chinese yam and roasted licorice, treats disorders arising from yin deficiency and blood depletion.

Goji berry-infused wine was highly revered in the Tang, Song and Yuan dynasties. Some ancient sources even claimed that it “cures all diseases” with no contraindications.

Emergency Prescriptions Worth a Thousand Gold Pieces (Bei Ji Qian Jin Yao Fang) states: “Take half a liter of goji wine on an empty stomach. After ten days, all diseases are cured. After thirty days, scars fade.”

Goji has long been regarded as a premium nutritious delicacy. Goji was an ingredient in three secret imperial prescriptions of the QIN Shi Huang era: the Youth-Restoring Pill, Seven-Treasure Hair-Restoring Elixir, and Longevity Consolidating Pill. FANG Xuanling, a chancellor of the Tang Dynasty, suffered mental and physical exhaustion from overwork.

Later, he persisted in eating goji and tremella soup and obtained desirable health-promoting effects. Goji was also a vital ingredient in the Longevity Ointment and Changchun Longevity Pellets taken by Empress Dowager Cixi of the Qing Dynasty. Traditional Chinese medicine has long held the theory of “health preservation with goji”, maintaining that regular intake of goji berries can “strengthen sinews and bones and build tolerance to cold and summer heat”. Therefore, it was commonly used as a nourishing, conditioning and anti-ageing food.

5. Historical changes in medicinal properties and producing regions of Goji

Collation and textual research based on ancient materia medica records reveal that the medicinal efficacy of goji berries has remained largely consistent from ancient times to the present. However, its nature and flavour underwent historical shifts: records alternately described it as bitter and slightly cold, sweet and neutral, sweet-bitter, sweet, bitter and cold, with a brief mention of sweet and warm. Since the Republic of China era, it has been generally recognized as sweet and neutral.

Table 2. Three stages of changes in nature and taste of Goji

Period	Record of nature and taste	Origin and location
Han Dynasty	Bitter and cold in taste	<i>Shennong's Classic of Materia Medica</i> 《神农本草经》 recorded that the root (<i>Cortex Lycii</i>) of goji is originally <i>L. chinense</i> , and the fruit is small and bitter.
Five Dynasties to Ming Dynasty	Alternation between sweet-neutral and slightly cold	<i>Treatise on Medicinal Properties</i> was the first book to record “sweet and neutral”. <i>Materia Medica for Famine Relief</i> first put forward two viewpoints on nature and flavor. Later editions included both species of <i>L. chinense</i> (Chinese goji) and <i>L. barbarum</i> (Ningxia goji).
Ming and Qing Dynasties to the Republic of China era	Sweet and neutral (Sweet-neutral)	The dry fruit of <i>L. barbarum</i> L. became the main part of medicine. The fruit had no bitter taste, and goji trees were widely cultivated. Finally, the flavor of sweet-neutral was established.

Ancient understanding of high-quality goji producing regions underwent several changes as follows:

In the *Supplement to the Essential Prescriptions Worth a Thousand Gold Pieces*, SUN Simiao of the Tang Dynasty stated that “authentic goji comes from Ganzhou”. Ganzhou corresponds to present-day Zhangye in Gansu Province, located in the middle section of the Hexi Corridor, which established Ganzhou as the authentic geo-authentic producing region.

Notes on the Principles of Things (Wuli Xiaoshi) of the Ming Dynasty recorded: “Xining goji fruits have less seeds but sweet-tasting, while fruits from other regions have abundant seeds.” “Goji trees grow everywhere in HuiAnPu, ripening in autumn.”

The *Zhongwei County Annals*, compiled during the Qianlong reign of the Qing Dynasty, notes: “In the NingAn area, every household maintains goji gardens. The sweet goji used medicinally across all provinces is produced in Ningxia.” From the Ming and Qing dynasties onward, it became widely acknowledged that goji from Zhongning, Ningxia Province, possessed superior quality.

As a medicinal-edible cash crop, goji evolved from wild utilization and artificial domestication to adaptive cultivation. SHEN Kuo (Northern Song Dynasty) wrote in *Dream Pool Essays*: “Goji from remote Shaanxi border areas grows over ten feet tall, thornless, with thick bark and superior sweet taste.” Despite knowledge of asexual propagation in the Tang Dynasty, seed propagation prevailed in the Yuan Dynasty, limiting ancient goji production.

Compilation of Ningxia Provincial Construction Reports (1936, the 25th year of the Republic of China) contained abundant photographs and texts depicting goji harvesting and cultivation practices of that period. In 1945 (the 34th year of the Republic of China), the goji planting area in Zhongning County reached 1,600 mu with a total output of about 50,000 kg. In 1949 (the 38th year of the Republic of China), the planting area expanded to 2,808 mu, while the total output dropped to only 35,000 kg. The planting area of Ningxia goji peaked at 800,000 mu around 2014 and has now stabilized at 230,000 mu, with a dried fruit yield of 50,000 tons.

Zhongning County was awarded several honors: In 1961, it was designated by the State Council as China’s only national goji production county. In 1995, it was awarded the title of “Hometown of Chinese Goji”. In 2001, the trademark “Zhongning Goji” was approved by the State Administration for Industry and Commerce, becoming the nation’s first trademark named after the origin of goji.

By the end of 2024, the planting area of *L. barbarum* was 1,592,700 mu, and the total output of dried fruits was 299,600 tons. The four major production areas contribute more than 95% of the national output in total:

Table 3. Production of Goji in four major production regions.

Production area	Planting area (10000 mu)	Percentage of the National Area	Industrial characteristics
Gansu	69.34	43.5%	The largest production area in the country, mainly in the Hexi Corridor (Jingyuan and Guazhou), with the dry fruit output ranking first in the country.
Qinghai	46.00	28.9%	Qaidam Basin, the largest organic Goji base in China.

Ningxia	22.87	14.4%	Daodi production area, focusing on improving quality and efficiency, is the core of the brand.
Xinjiang	20.00	12.6%	Jinghe is the main production area, mainly producing round fruits.

In addition, *L. ruthenicum* is mainly cultivated in Xinjiang and Golmud and Nuomuhong regions in Qinghai. Fruit cultivation areas of *L. chinense* are gradually reduced (Hebei Julu County and other places has rarely cultivated farms, but South Korea has regional cultivation), but vegetable cultivation areas are very extensive (Guangdong, Fujian, Ningxia, Xinjiang, Shandong and other places).

6. Cultivated varieties and development trend of Goji

The National Goji Germplasm Repository is located in Yinchuan, Ningxia Province, and was constructed under the auspices of the Goji Science Institute, Ningxia Academy of Agriculture and Forestry Sciences. It is the world's largest in-situ conservation base for living germplasm of the genus *Lycium*. First established in 1985, the repository was officially recognized as a national-level germplasm repository in 2022. Equipped with a low-temperature germplasm bank, it has built a three-in-one conservation system comprising living plants, seeds and specimens. It conserves a total of 2,662 accessions belonging to 18 species of the genus *Lycium*, including wild species, landraces, selectively bred lines and exotic introduced materials. The repository mainly carries out the collection, conservation, identification, evaluation and innovative utilization of goji germplasm resources. It supports goji genome research, new variety breeding and innovation of germplasm resources. Additionally, regional germplasm repositories were established in Qinghai Province, Xinjiang Province, and Chinese Academy of Sciences.

China's goji breeding has established three specialized cultivar groups: red-fruit, black-fruit and vegetable-type goji. Major breeding teams include the Goji Science Institute (Ningxia Province), South China Botanical Garden (Guangdong Province), Qinghai University (Qinghai Province) and Inner Mongolia Black Goji Engineering Research Center (Inner Mongolia Autonomous Region).

For red-fruit cultivars: The Ningqi series dominates red-fruit production, including 'Ningqi No.1' (widely adaptable, stable yield); 'Ningqi No.7' (self-compatible, high premium fruit rate, the most widely planted cultivar). Other cultivars such as 'Ningqi No.3/5', 'Ningnongqi No.9/15' and 'Keqi 6082' fit large-fruit cultivation, mechanical harvesting and fresh-keeping drying processing. Yellow-fruited cultivars 'Ningnongqi No.19 and 20' are developed for juice production. South China Botanical Garden, Chinese Academy of Science, developed cultivars: 'Zhongke Lvchuan No.1' (juice/fresh eating), 'Zhongke Huangqi No.1' (yellow fruit), 'Bairuiyuan No.1' (multi-locular), and 'Zhongke Dingqi No.1' (uniform ripening, apical termination). Regional cultivars were also developed for Qinghai and Xinjiang Provinces.

For black-fruit cultivars: Black goji has long relied on wild resources. Its artificial domestication and breeding started relatively late in recent years, resulting in a small number of cultivars. The black goji cultivars that have obtained plant new variety rights (PVP) issued by the National Forestry and Grassland Administration are as follows. ‘Ningnong Heiqi No.1’ (also named Ningheiqi No.1). The first cultivated improved black goji cultivar granted new variety rights in China, with significantly higher anthocyanin content than wild germplasm. ‘Rongqi No.1’ has multi-colored thornless fruits, which is good for both suitable ecological restoration and ornamental use. ‘Linqi No.1’ and ‘Linqi No.5’ with light purple fruits, are salt-alkali tolerant; ecotype black goji.

For vegetable-type cultivars: Leaves of both *L. barbarum* and *L. chinense* can be used for leaf vegetables and teas. ‘Ningqicai No.1’ is first vegetable-use *L. barbarum* cultivar registered with the Ministry of Agriculture and Rural Affairs. ‘Ningqicai No. 2/3/4/9’ (*L. barbarum*) have obtained plant new variety rights from the National Forestry and Grassland Administration, and they are suitable for both vegetable and leaf tea. ‘Tianjing No.3’ (*L. chinense*) is diploid and mixoploid vegetable-use goji, featuring broad leaves, few thorns, high yield of young shoots, immunity to gall mites, and high resistance to powdery mildew and root rot. ‘Yuxuan No.1’ (*L. chinense*) is a vegetable-use cultivar in Guangxi, being heat- and humidity-tolerant and adapted to open-field cultivation in South China.

Development trend: Goji breeding is shifting from single fruit-oriented breeding toward diversification covering fruit-use, black-fruit and vegetable-use types. Cultivars are becoming increasingly specialized and functional. Cultivation modes are transforming from extensive planting to standardized, mechanized and protected agriculture. The industrial pattern takes Ningxia as the brand core, while Gansu and Qinghai serve as major raw material producing regions. The whole industry has entered a high-quality development stage featuring reduced planting area, increased yield per unit area and improved product quality.

7. Drying methods of Goji fruits

There are five mainstream drying methods for goji berries: natural sun drying, heat pump drying, low-temperature vacuum drying and freeze drying, which differ greatly in technical characteristics and applicable scenarios. Furthermore, different drying methods greatly affect price and bioactive contents.

Natural sun drying: No fixed temperature control; drying depends on ambient temperature, normally ranging from 20 to 35 °C. It is highly susceptible to weather fluctuations. Fruit surface temperature may temporarily exceed 40 °C at noon. The drying process is slow with uncontrollable temperature. Strong light and high temperature tend to trigger the degradation of pigments and goji polysaccharides. This method easily causes degradation of bioactive components and inconsistent fruit quality, and is only suitable for extensive processing by small-scale individual growers.

Heat pump drying: Temperature is controlled within 40–55 °C, representing a moderate and low-temperature drying method. Compared with conventional hot-air drying (45–60 °C), it operates at a lower temperature with simultaneous humidity regulation. The typical setting is 45–50 °C with gentle heating. The finished product retains more active components than that from ordinary hot-air drying. It offers excellent cost-performance, making it the preferred process for current large-scale industrial production.

Low-temperature vacuum drying (vacuum drying): The material temperature stays ≤ 30 °C. Moisture evaporates at low temperature under low pressure. Thanks to the low environmental temperature, high-temperature oxidation is nearly eliminated, so heat-sensitive

bioactive substances such as goji polysaccharides and carotenoids can be preserved to the maximum extent. This is also called fresh-locking drying method, and product color is very well preserved.

Freeze drying (lyophilization) : Pre-freezing at $-35 \sim -40$ °C to fully freeze water inside goji berries. In the primary sublimation drying under vacuum, the material temperature stays below 0 °C. The desorption drying for bound water removal is controlled at no higher than 30 °C. The cold trap temperature is generally $-45 \sim -50$ °C to capture water vapor.